A DoppleScAnt

Lost any transmitters lately? Find them even when simple methods fail by using a Doppler Scanning Antenna. Ham ingenuity is far from dead, as this project demonstrates.

By Terrence Rogers,* WA4BVY

When our repeater society decided to sponsor a 2-meter transmitter hunt, a buddy and I joined in enthusiastically. Rochester, NY (where I lived at the time), is a high-technology area so we were correct in expecting a high level of competition. A minimum of a Yagi beam, a portable receiver with limiter meter, and good terrain maps seemed to be the order of the day. Although we expected to place well up in the standings, our best finish using the traditional Yagi method was fifth out of 13. This would not seem a humiliating defeat until you consider that we are comparatively poor losers!

A New Method of Direction Finding

A local university library provided the first directions toward a better solution, with a short paragraph about Doppler antennas. The theory of operation is reasonably simple. Radio signals received on a rapidly moving antenna experience a frequency shift due to the Doppler effect, an effect well known to anyone who has observed a moving car with its horn blowing. The radio-frequency shift may be detected by a frequency-modulation receiver which, of course, is the type most often used on 2 meters. The rapid antenna movement can be simulated with a special antenna array and a scanning adaptor, while the audio output of the receiver is analyzed to provide the direction of the received signals, based on the Doppler shift.

Fig. 1 shows a quarter-wave antenna being rotated in a circle about point P, with some constant angular velocity, omega (ω). The instantaneous tangential velocity of the antenna is $V = \omega \times R$. As the antenna approaches the transmitter, the received frequency will be shifted higher. The highest frequency is achieved when the antenna is exactly at point A with maximum tangential velocity toward the transmitter. Conversely, the lowest frequency occurs when the antenna is at point C, with maximum velocity away from the transmitter. The amount of frequency shift due to this Doppler effect is proportional to the channel frequency and the tangential velocity, which is itself a function of the radius R and the angular velocity.

Fig. 2 shows a plot of v_t, the component of the tangential velocity in the direction of the transmitter. Comparing Figs. 1 and 2, notice that at B in Fig. 2 v_t is crossing zero from the positive to the negative and the antenna is closest to the transmitter. The Doppler shift and consequent audio output from the receiver discriminator follow the same plot so that a negative-slope, zero-crossing detector will locate the direction of the transmitter.

The relationship between v_t and the Doppler shift is quantitatively:

$$f' = \frac{f(c \pm v_t)}{c} \qquad \text{(Eq. 1)}$$

where: f' = Doppler-shifted frequency
f = transmitter frequency
v_t = velocity of antenna toward or away from the transmitter
c = speed of light

Solving for the actual Doppler shift of $f \pm f'$ yields

$$\Delta f = \frac{f v_t}{c} \qquad \text{(Eq. 2)}$$

Since $v_t = v \cos\Theta$

$$f = \frac{f v \cos\Theta}{c} \qquad \text{(Eq. 3)}$$

where $\Theta = 0$ at A in Fig. 1

For example, we could find how fast an antenna would have to rotate to give a 147-MHz transmitter a 1-kHz Doppler shift. First, solve Eq. 2 for v_t:

$$v_t = \frac{\Delta f c}{f} = \frac{1\text{ kHz} \times 3 \times 10^8}{147 \times 10^6}$$

$= 2000$ m/s (Eq. 4)

This is about six times the speed of sound, making the mechanical rotation of the antenna impractical. When this type of antenna is connected to an fm receiver a tone is heard. Knowing that $v = \omega R$, we can solve for ω when R is 0.5 meters. $\omega = 4000$ radians/second, or 637 Hz.

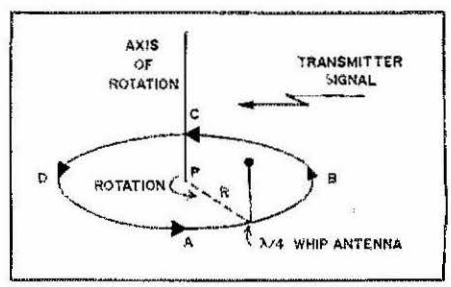
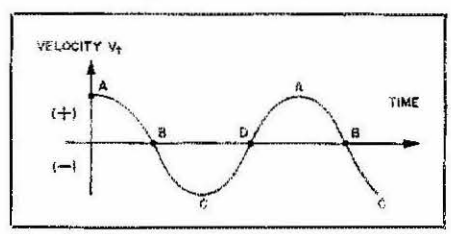


Fig. 1 — Pictorial diagram of the theoretical Doppler antenna, circling at six times the speed of sound.

Fig. 2 — This graph illustrates the frequency shift related to antenna movement toward and away from the signal source. *Both* antenna rotation and signal are time-based.



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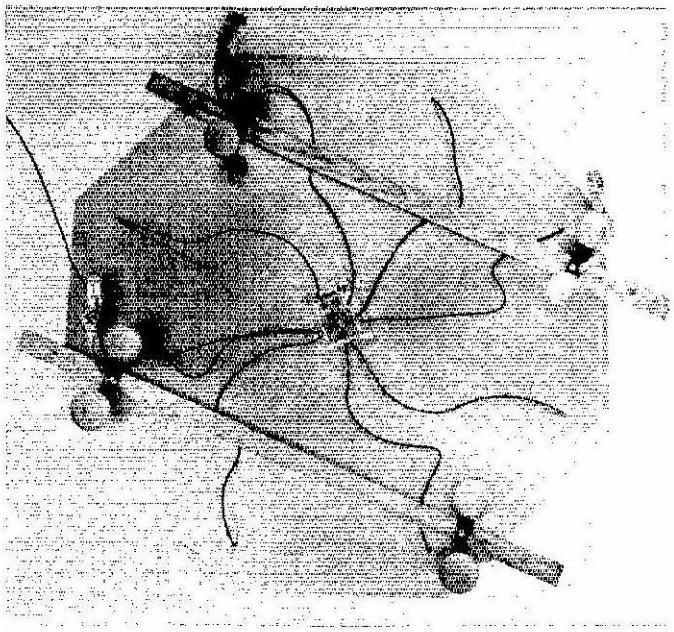
Shown here is the former Mustang II, along with the author and the Doppler antenna system. The pole-mounted whip for 2 meters had no effect on the Doppler system.



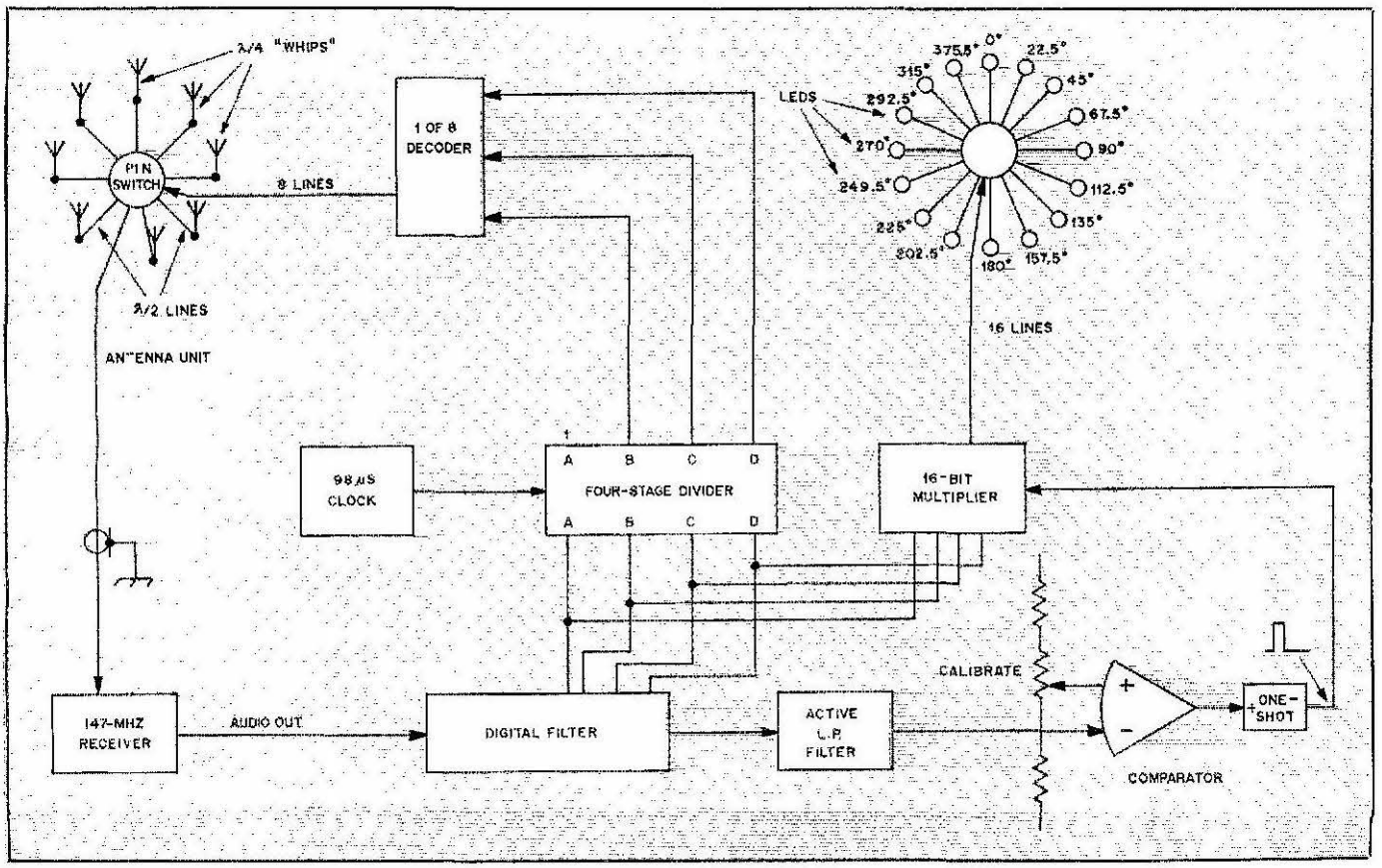
An underside view of the Doppler antenna mounting plate; note the eight equal lengths of small coaxial cable. The PIN diode circuitry is on the circuit board in the center.

Now refer to the system diagram in Fig. 3. The rotation is accomplished by constructing an array of eight antennas equally spaced in about a one-meter (half-wavelength) diameter circle. Any greater diameter leads to an ambiguity in direction. The antennas are then electronically scanned in sequence to approximate the rotation of a single antenna. We used PIN diodes to connect the individual antennas, since they allow us to stop the scan and transmit through the antenna system. The PIN diodes are capable of conducting more rf current than the dc bias current would indicate, whereas ordinary signal diodes will work but not conduct any appreciable rf current.

How the DoppleScAnt Works

Eight antennas are scanned in 1.57 milliseconds, so the clock must operate at

Fig. 3 — System diagram of the Doppler direction finder.



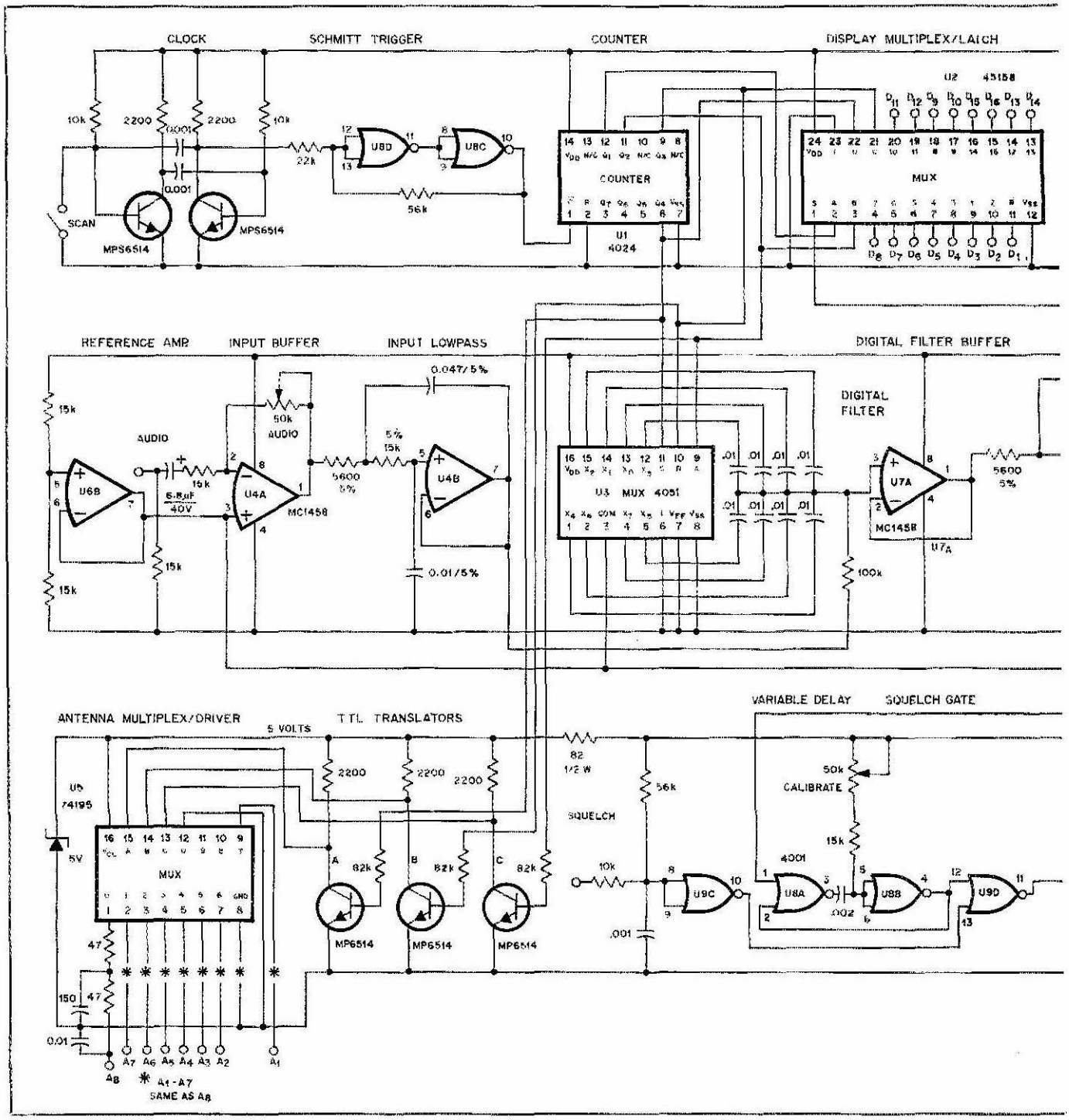


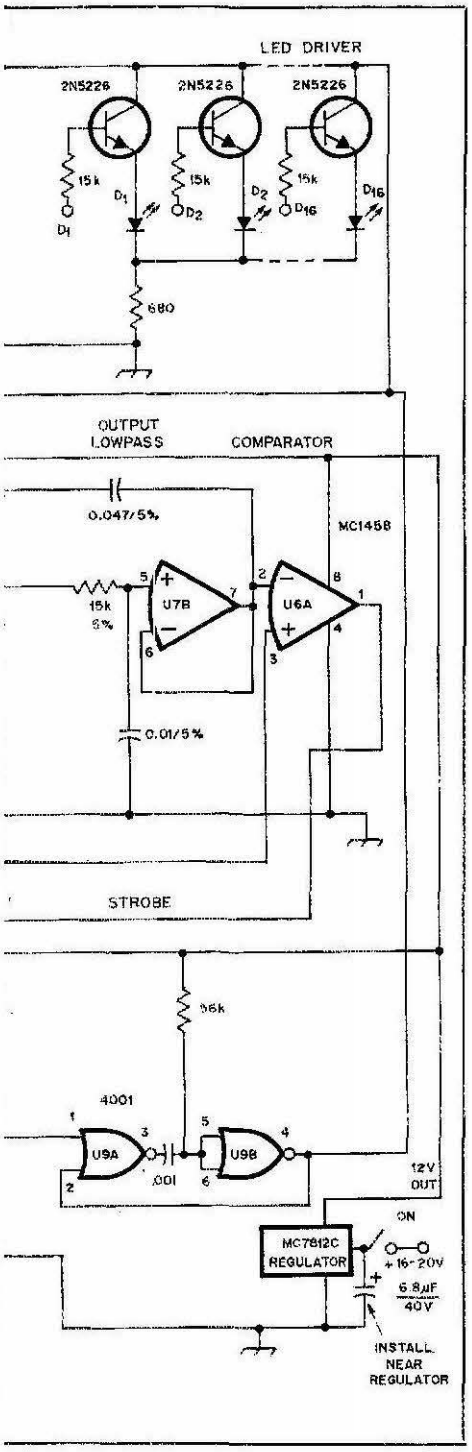
Fig. 4 — Schematic diagram of the control unit used in the vehicle. All resistors are 1/4 watt, 10 percent, unless otherwise noted; capacitor values less than one are in μF, more than one in pF unless electrolytic. All electrolytics are in μF. All capacitors are 20-percent tolerance unless noted. Connect pin 7 of each U8 and U9 to VSS and pin 14 to VDD.

1.57 + 8 or 196 microseconds. We actually chose 196 + 2 microseconds since our compass rose has 16 positions. The 637-Hz tone must be extracted from the composite audio output of the receiver by a narrow filter. However, such a narrow filter introduces considerable phase distortion with just a little mistuning. Therefore, we used a digital filter which is operated by the same clock that controls the scanning. The effect is to have a filter automatically centered on the scan tone even when there is some frequency drifting. A residual phase shift caused by the audio circuitry is calibrated out of the system.

How does the circuit work? Q1 and Q2 form a flip-flop operating at 16 times the scan rate of 600 Hz, or 9600 Hz. The RC waveform output is converted to square waves by the Schmitt trigger formed from U8C and U8D. The scan may be stopped for transmitting by closing the switch.

U1 is a seven-stage ripple counter, of which only the first four stages are used. The Q1, Q2, Q3 and Q4 outputs of U1 are all connected to U2, a four-bit latch and 4-to-16 line decoder. U2 is used to scan the LED display compass rose and to latch an output *only* when a pulse appears at pin 1, the strobe input from the calibrate single shot.

The LEDs are actually driven by 16 pnp switching transistors Q3-Q18, needed because of the low current output of the CMOS IC. All the LED directional



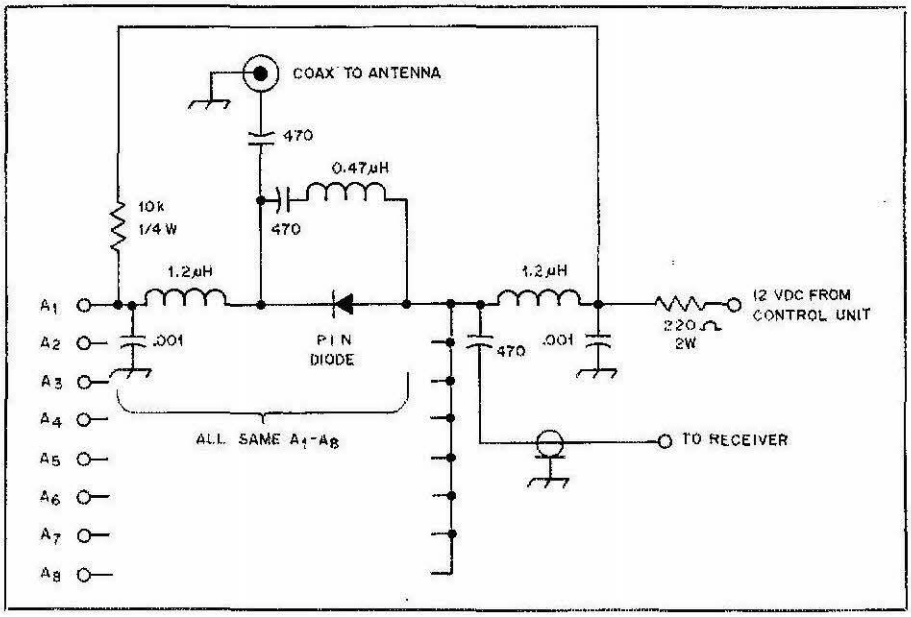


Fig. 5 — Schematic diagram of the PIN diode circuitry mounted beneath the antenna; eight identical circuits are used.

displays have a common current-limiting resistor, R61, since only one LED is on at a time. The diodes are mounted in a circle every 22.5 degrees on the front panel with D1 at the top (zero degrees) and proceeding counterclockwise (the same direction as the antenna is scanned). Number "one" antenna is usually at the right but its exact position is determined in the final test.

U6B is used to provide a stiff source for reference bias for the other op amps. Audio input is to U4A, which is an adjustable buffer amplifier. It is set so that at typical levels of audio from the transceiver, clipping does not occur at pin 1 of U7A, which is the buffer for the digital filter. This is about 1.6 V rms when an 8-volt supply is used. U4B is a low-pass filter which reduces voice audio peaks and overloading to the digital filter.

U3 is fed by outputs Q2, Q3 and Q4 of U1, so a complete cycle for its eight outputs occurs in step with the 16-step cycle of U2. This eight-way-decoded, bidirectional multiplexer is connected as a digital filter with a bandwidth of 10 Hz or less. The stepped output of the digital filter is smoothed by U7B, another low pass.

U6A is a comparator connected to go positive on a negative half of the sine-wave input. This fires the variable single-shot of U8A and U8B. This is used to calibrate out variations between radios, component aging, and so on. A second short-pulse single-shot is formed from U9A and U9B; it fires on the fall of the calibrate single-shot and provides the latching pulse to U2, which then illuminates whatever LED position was decoded at the time of the pulse for the next cycle.

U5 is the only TTL circuit. Its drive comes from Q2, Q3 and Q4 of U1 for the same reasons that U3 is so connected. The CMOS level is translated to TTL levels by Q19, Q20 and Q21. The outputs are open collector and are rated to drive the PIN diodes in the antenna unit directly.

The single-shot which latches the LED display drive may be gated on and off by the receiver squelch. This connection to U9C is labeled SQUELCH and is arranged so that a low potential produces the gating which locks in the current display. This allows the unit to lock on very short transmissions of about 250 ms after the squelch opens. The digital filter is quite narrow and so the sine-wave output usually does not decay to unusable levels by the time the typical squelch has closed.

Fig. 4 is a schematic diagram of the control (adaptor) unit used in the auto. A control cable goes to the antenna unit, which is mounted on the roof with cartop carriers. The circuitry shown in Fig. 5 is mounted on the underside of an aluminum plate which forms the groundplane for all antennas. Aluminum plate of 0.0625 inch (1.6 mm) thickness is quite adequate. The antennas used are commonly available quarter-wave whips. These antennas must be identical, especially in length. The interconnecting half-wavelengths of coaxial cable must all be of the same brand and the same length to within about one-quarter inch.

The capacitor and coil combination around the PIN diodes forms a parallel-resonant circuit with the capacitance of the diodes to increase isolation from "off" units. Note that changing the diode will change the value of the coil. This circuit may be checked with a grid-dip meter. It is not too critical and might be left out with low capacitance diodes. The commonly available Motorola MPN3402 diodes survive a 25-watt, 2-meter transmitter signal if the scan is stopped when one transmits.

Following construction and preliminary trials, the unit should be taken to an open field for calibration. Adjust the audio gain control at a comfortable speaker level, taking care not to overload the digital or low-pass filters (8 volts pk-pk). Set the calibrate control in the middle of its range. A 2-meter (or other band used) transmitter is placed some distance off

and the antenna array rotated until the compass rose reads true relative to the direction of the vehicle.

For aesthetics, the antenna may be rotated a slight amount before it is drilled and secured to the cartop carriers. Then the calibrate control may be adjusted to compensate for this movement. A walk around the auto with a handheld transceiver will reveal if the installation is functioning properly.

We first used a cable connector between the adaptor and the antenna unit which was not polarized. At one of the following practice sessions when the plug was reversed, the driver was instructed to follow the signal into Lake Ontario! Under such conditions the indicator reads correctly ahead and behind but reverses left and right, so it is best to check with a walk-around. Once calibrated in one direction, we did not find it necessary to compensate in other directions to the limit of readout accuracy. We left the pole-mounted, 2-meter antenna on the rear bumper during the tests and found no significant interaction.

Finding Bunnies

Use of this system does demand some skill. When driving down a street one may notice that the display will "dash around" the compass rose. This indicates the presence of multipath reflections that the Yagi competition will also have to weed out. You, however, will know that you are in a high-reflection area, whereas they often do not. If the car is stopped in a reflection the tone will sound distorted (tinny). Rock the car for the best note and then take the reading. You can also remain in motion, which is the best strategy, and have a companion watch the display. Every two or three seconds in a high-reflection area the display will momentarily come to rest. This reading is invariably accurate.

As time goes on and the competition becomes aware that you are using the DoppleScAnt, some countermeasures will have to be brought into play. Encourage the "rabbit" to reduce the time the hidden transmitter stays on the air. Since the system will lock on a bearing in about 250 ms you can find a hidden transmitter which is nearly "off the air" completely. You have just eliminated your Yagi competition!

Our targets tried power and polarization switching to throw us off. The first time that happened our team was not aware of it until we actually found the transmitter, because the system makes no use of amplitude or polarity information. Next, high power was used, as this causes the attenuators used by other contestants to be turned all the way up in the vicinity of the hidden transmitter, so that signals enter the receiver directly and the Yagi becomes useless. This trick is ineffective against the "octopus" system because it does not use an attenuator.

Finally, the sly devils tried transmitting a 600-Hz tone. This might have been effective but the digital filter is only 4 Hz wide and the rabbit does not know what exact frequency the clock is on, due to the tolerances of the components. We also realized that we could adjust the regulator voltage so the pitch changed slightly to avoid the interference.

Some remarks on strategy should be a fitting end to this article. It is sometimes of benefit not to drive immediately in the direction indicated, but rather at quite an angle to it, so that the approximate location of the bunny may be determined by "triangulation" as soon as possible. This will allow a course to be plotted to avoid the general flow of traffic and accompanying delays. The higher accuracy of the "octopus" should allow you to do this in situations where the small portable Yagis will not suffice.

We found that a three-person team is best: a driver, an equipment operator and a strategist. The driver pilots the auto while the operator sees to "calling" the bunny and interpreting the display. (The pictured Mustang II no longer exists, as a result of driver error while said driver was watching the electronics.) The operator also adds the relative bearing to the magnetic bearing of the car and thus obtains the magnetic bearing to the transmitter. The strategist then plots this information, discarding older, more distant (and thus less accurate) bearings, as the hunt progresses. The strategist is also responsible for the first coarse guess of the actual location, so that obstructions such as rivers with no bridges may be avoided in time. This task requires no technical expertise and is a good job to invite a nonham to do.

We found the DoppleScAnt to be our key to winning at an immensely entertaining club activity. If you have the competitive urge, get your club to start up a transmitter hunting program this spring; meanwhile, start building your "secret weapon!" QST

[Editor's Note: Photocopies of the circuit-board patterns provided by the author are available from ARRL hq. for one dollar (to cover handling) and a business-size stamped return envelope. The author has indicated that he can offer assistance in obtaining ready-made circuit boards and hard-to-find parts. A stamped return envelope sent to him will bring more information.]

Strays

Predicted Orbits for OSCAR 8

Ref. Orbit	Date	Time (UTC)	Long. W.	Ref. Orbit	Date	Time (UTC)	Long. W.
786	1 May	0130	61	1037	19 May	0121	59
800	2 May	0135	62	1051	20 May	0126	60
814	3 May	0141	64	1065	21 May	0131	61
827	4 May	0003	39	1079	22 May	0136	63
841	5 May	0008	41	1093	23 May	0142	64
855	6 May	0013	41	1106	24 May	0004	40
869	7 May	0018	43	1120	25 May	0009	41
883	8 May	0024	45	1134	26 May	0014	42
897	9 May	0029	46	1148	27 May	0019	43
911	10 May	0034	47	1162	28 May	0024	45
925	11 May	0039	48	1176	29 May	0030	46
939	12 May	0044	50	1190	30 May	0035	47
953	13 May	0050	51	1204	31 May	0040	49
967	14 May	0055	52				
981	15 May	0100	54				
995	16 May	0105	54				
1009	17 May	0100	56				
1023	18 May	0116	58				

Updated orbital information can be obtained from W1AW bulletins. For further information, see "Operating News," page 82.

A first — computerization of the 1978-1979 *ARRL Repeater Directory*. Editor WA1LOU is shown here proofing and duping the computer printout. This free membership service is now available from Headquarters for a 6 × 9-inch s.a.s.e. (46-cents U.S. postage). *(W1YL photo)*